



IXPE

Imaging
X-Ray
Polarimetry
Explorer

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE): OVERVIEW



Steve O'Dell (NASA Marshall Space Flight Center)
on behalf of the IXPE Team



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INTERNATIONAL PARTNERSHIP

| | |
|---|--|
|  <p>Marshall Space Flight Center</p> <p>PI team, project management, SE and S&MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving</p> |  <p>IAPS INAF INFN ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS</p> <p>Polarization-sensitive imaging detector systems</p> |
|  <p>Detector system funding, ground station</p> |  <p>LASP Mission operations</p> |
|  <p>Spacecraft, payload structure, payload, observatory I&T</p> |  <p>ROMA TRE Stanford University McGill MIT UNIVERSITA' DEGLI STUDI NATIONAL INSTITUTE FOR ASTROPHYSICS Science Working Group Co-Chair Co-Investigator</p> |

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SCIENCE TEAM

■ Co-Investigators

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■ Collaborators

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MISSION SUMMARY (1/2)

■ Mission background

- Imaging x-ray polarimetry in 2–8 keV band
- NASA Astrophysics Small Explorer (SMEX) selected in 2017 January

■ Orbit

- Pegasus-XL (airborne) launch in 2021, from Kwajalein
- Equatorial circular orbit at $\gtrsim 540$ km (620 km, goal) altitude

■ Flight system

- Spacecraft, payload structure, and integration by Ball Aerospace
 - Deployable payload boom from Orbital-ATK, under contract to Ball
- X-ray Mirror Module Assemblies by NASA/MSFC
- X-ray (polarization-sensitive) Instruments by IAPS/INAF and INFN



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MISSION SUMMARY (2/2)

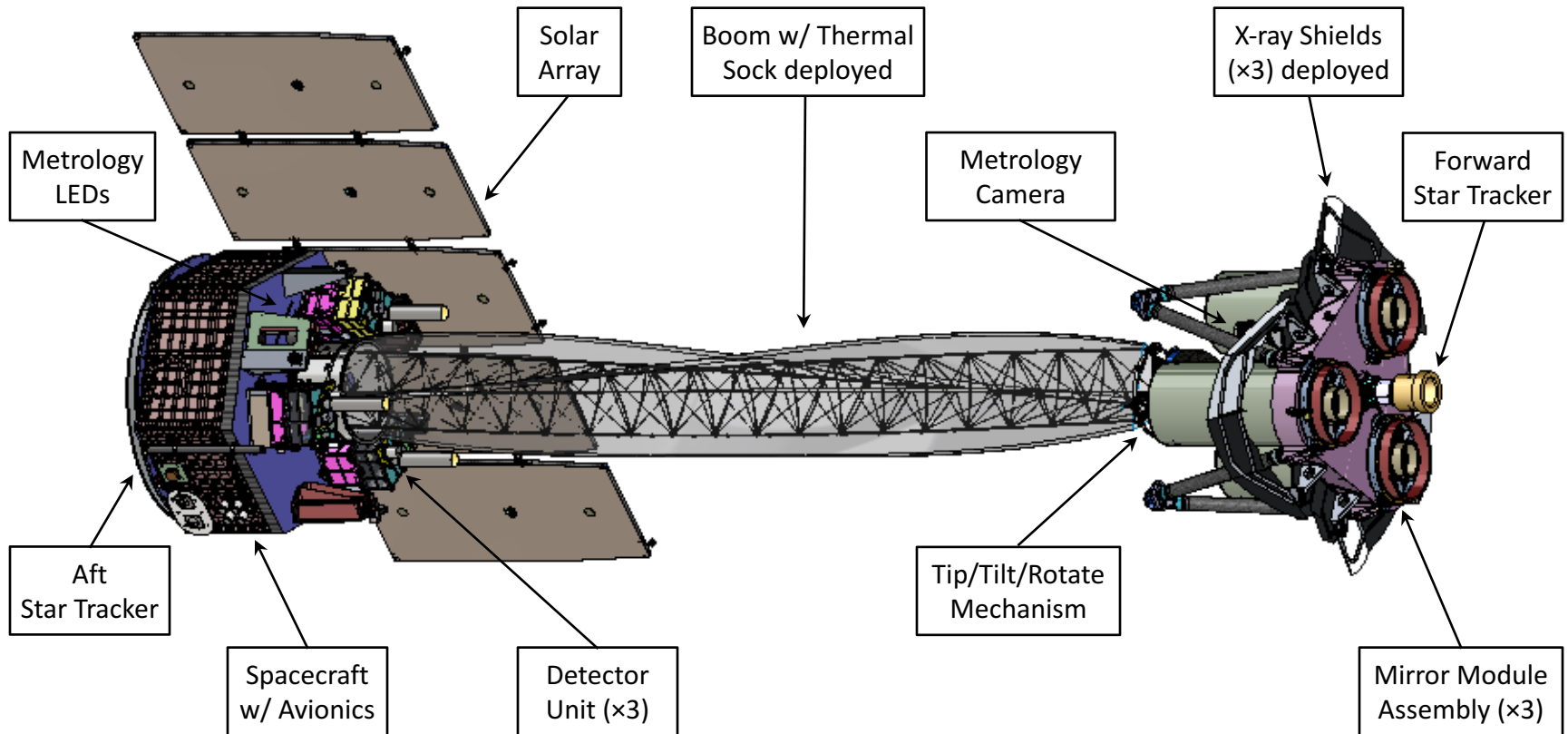
■ Ground system

- ASI Malindi ground station, with Singapore backup
- Mission Operations Center at LASP (University of Colorado)
- Science Operations Center at NASA/MSFC
- Data archive at HEASARC (NASA/GSFC), mirror at ASI Data Center

■ Science

- Active galactic nuclei
- Microquasars
- Isolated pulsars and pulsar wind nebulae
- Supernova remnants
- Magnetars
- Accreting x-ray pulsars

MAJOR COMPONENTS OF THE OBSERVATORY

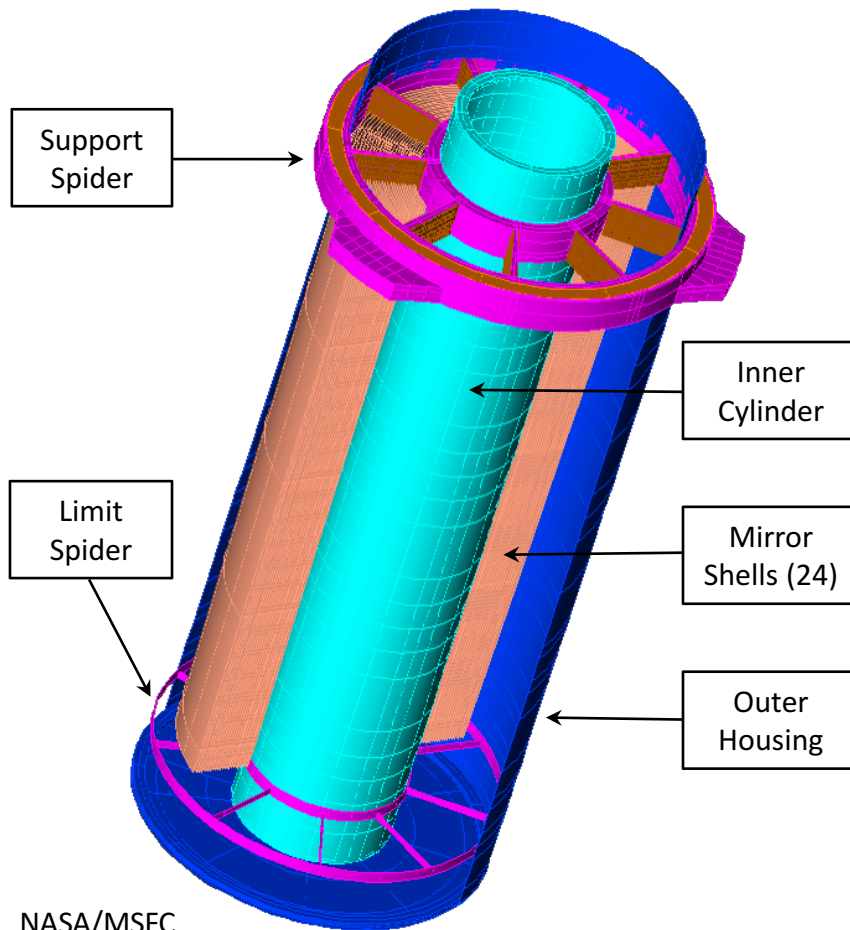


← 5.2-m total length deployed →

Ball Aerospace

← 4.0-m focal length →

MIRROR MODULE ASSEMBLY (MMA)



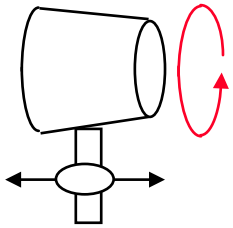
| Property | Value |
|----------------------------------|--|
| Number of MMAs | 3 |
| Mirror shells per MMA | 24 |
| Focal length | 4000 mm |
| Shell length (P+S combined) | 600 mm |
| Inner-outer shell diameter | 162–272 mm |
| Inner-outer shell thickness | 0.18–0.26 mm |
| Shell material | Nickel–Cobalt alloy |
| Mass per MMA | 30 kg (current best estimate) |
| Effective area per MMA | 210 cm ² (2.3 keV) > 230 cm ² (3–6 keV) |
| Angular resolution | ≤ 25 arcsec HPD |
| Field of view (detector-limited) | 12.9 arcmin |

NASA/MSFC

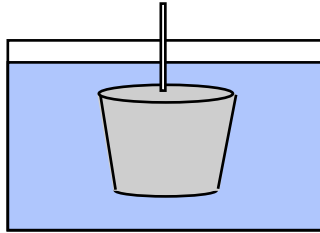
MIRROR PRODUCTION PROCESS

Mandrel fabrication

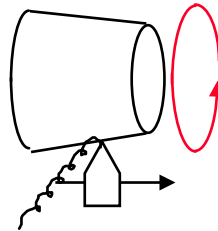
1. Machine mandrel from aluminum bar



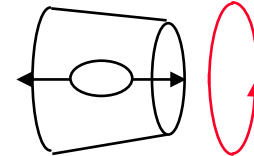
2. Coat mandrel with electroless nickel (Ni-P)



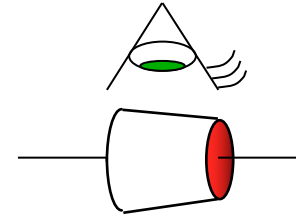
3. Diamond turn mandrel to sub-micron figure accuracy



4. Polish mandrel to 0.3-0.4 nm RMS

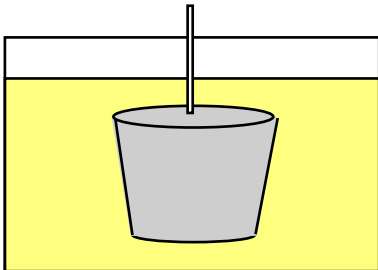


5. Conduct metrology on the mandrel

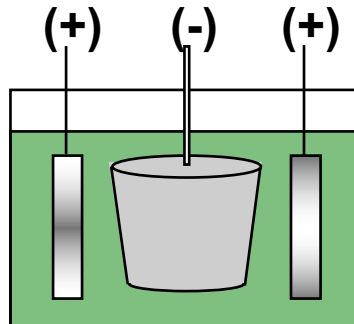


Mirror-shell forming

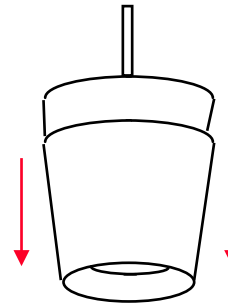
6. Passivate mandrel surface to reduce shell adhesion



7. Electroform Ni-Co shell onto mandrel



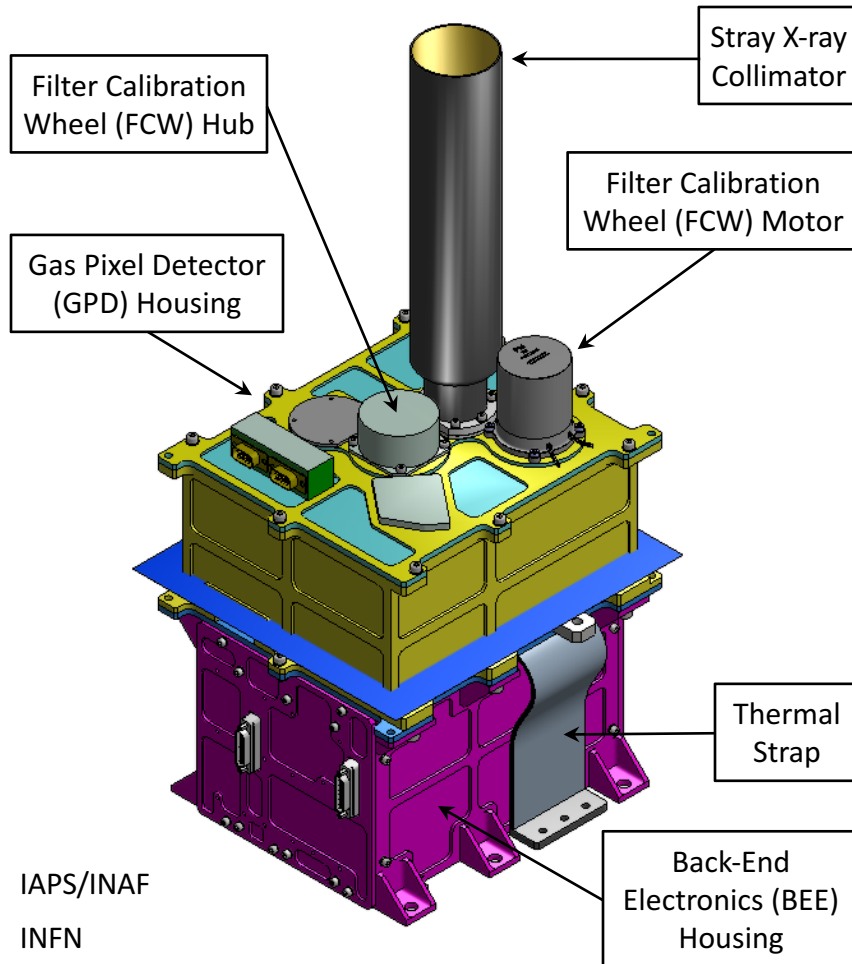
8. Separate shell from mandrel in chilled water



Ni-Co electroformed mirror shells

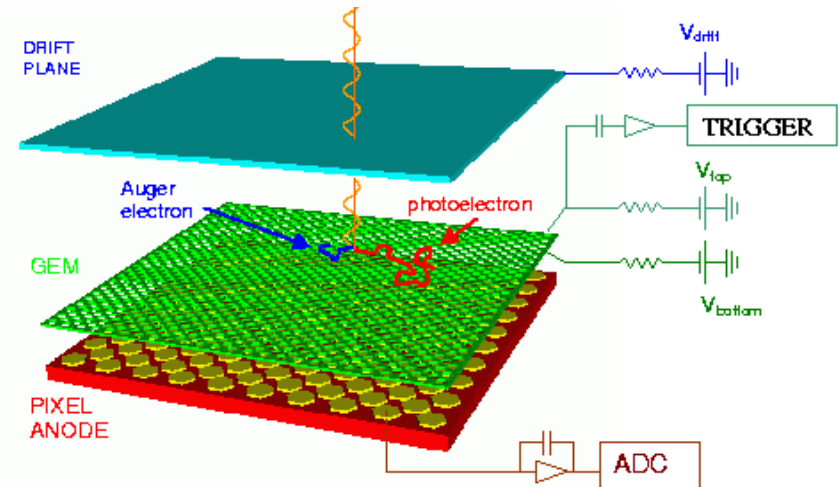


INSTRUMENT DETECTOR UNIT (DU)



Gas Pixel Detector (GPD)

- Polarization sensitive
 - Initial photoelectron direction correlated to electric field

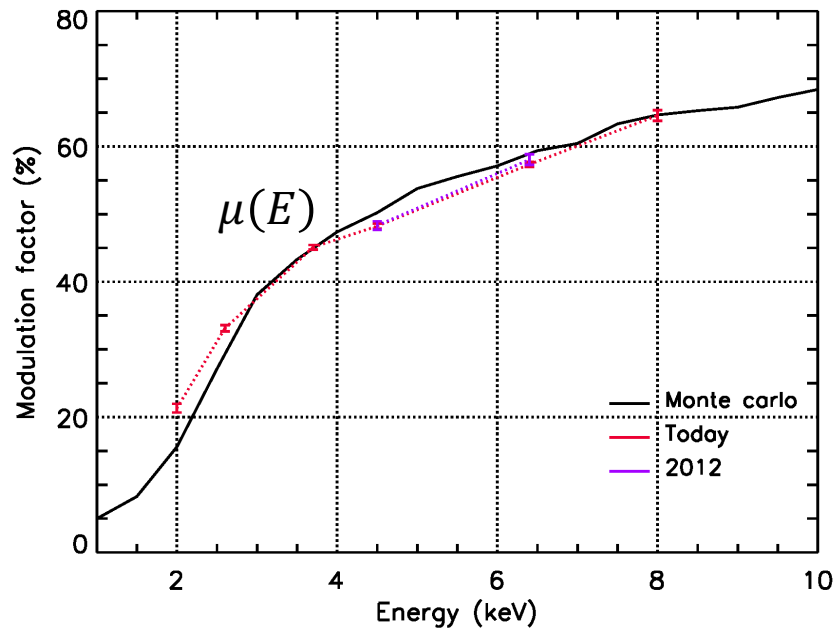


$$\frac{\partial \sigma}{\partial \Omega} = r_0^2 \frac{Z^5}{137^4} \left(\frac{mc^2}{h\nu} \right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1 - \beta\cos(\theta))^4}$$

POLARIZATION FROM MODULATION HISTOGRAM AND CALIBRATED MODULATION FACTOR

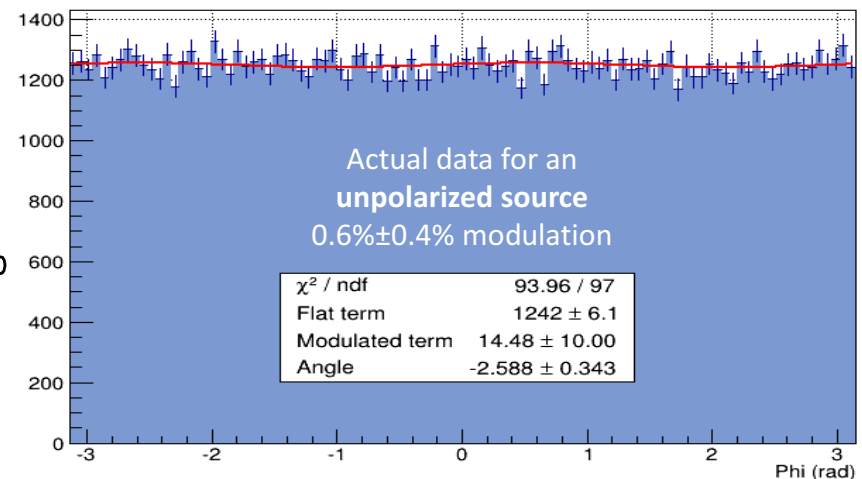
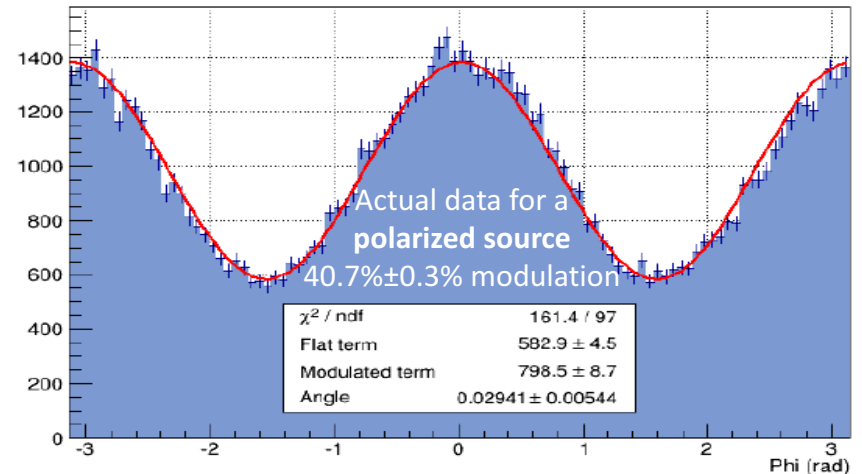
■ Polarization degree

- $\Pi = \text{Modulation} / \mu(E)$

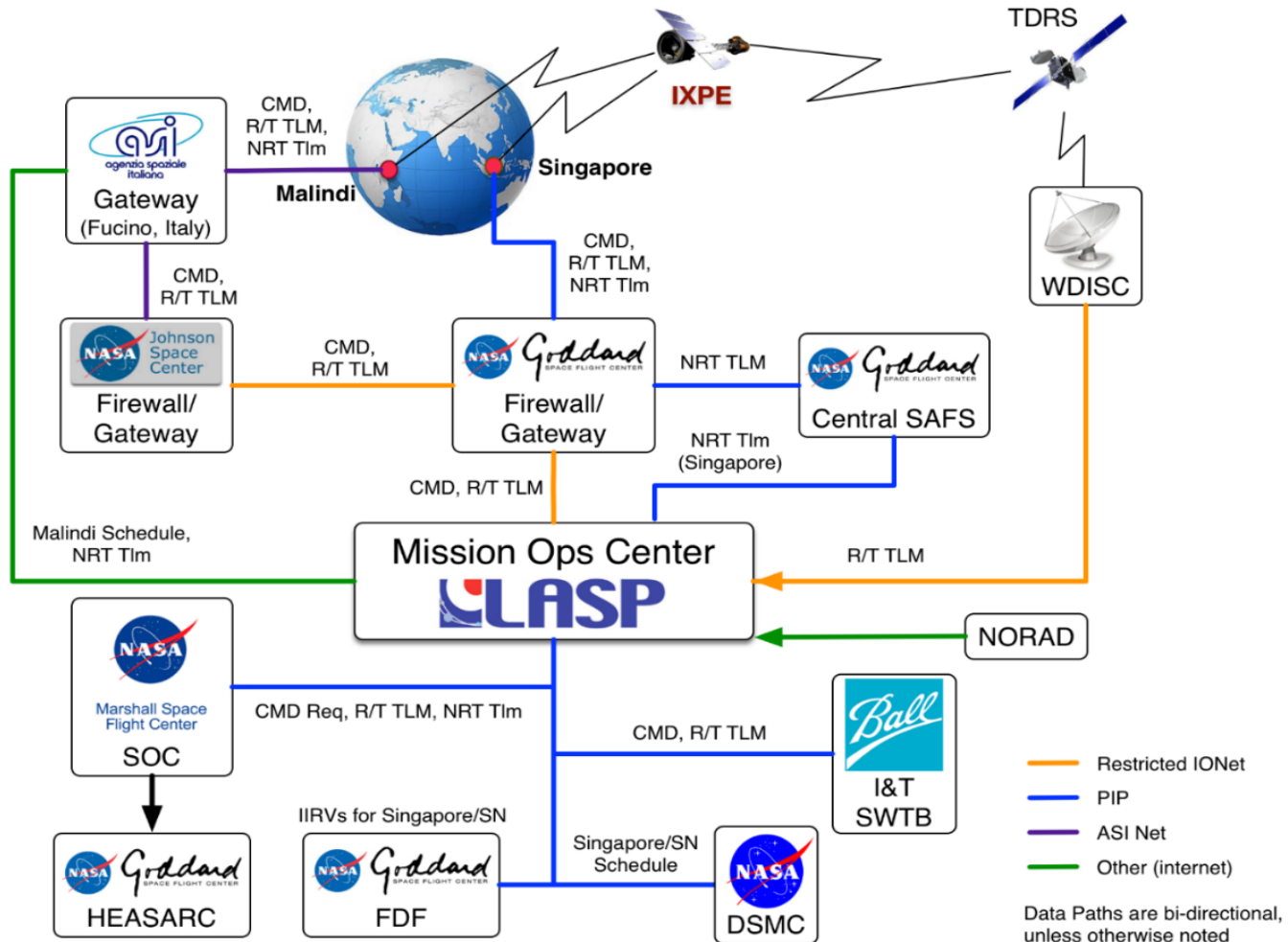


IAPS/INAF (Istituto di Astrofisica e Planetologia Spaziali / Istituto Nazionale di Astro Fisica)

INFN (Istituto Nazionale di Fisica Nucleare)

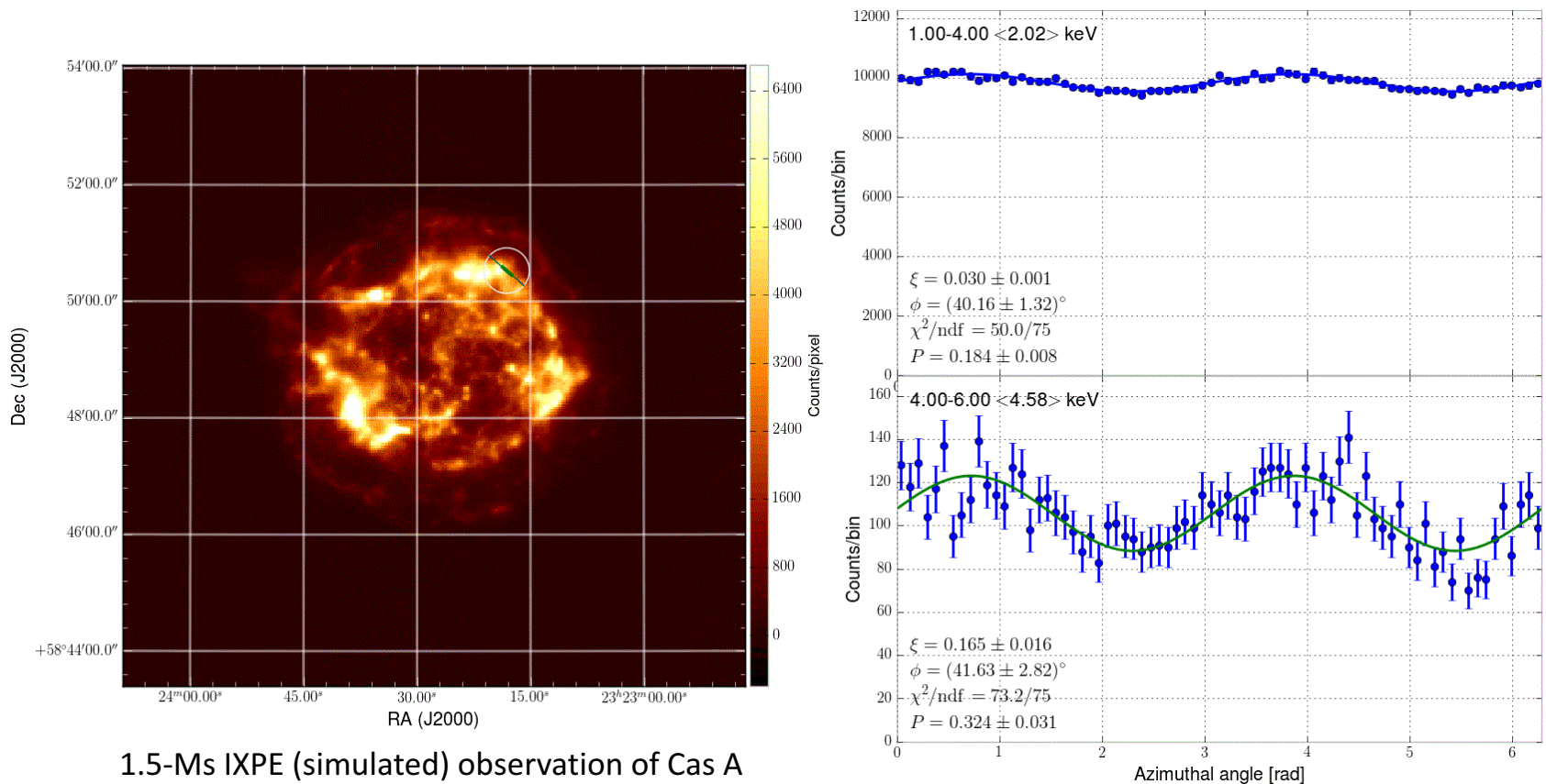


GROUND SYSTEM: CONCEPT OF OPERATIONS



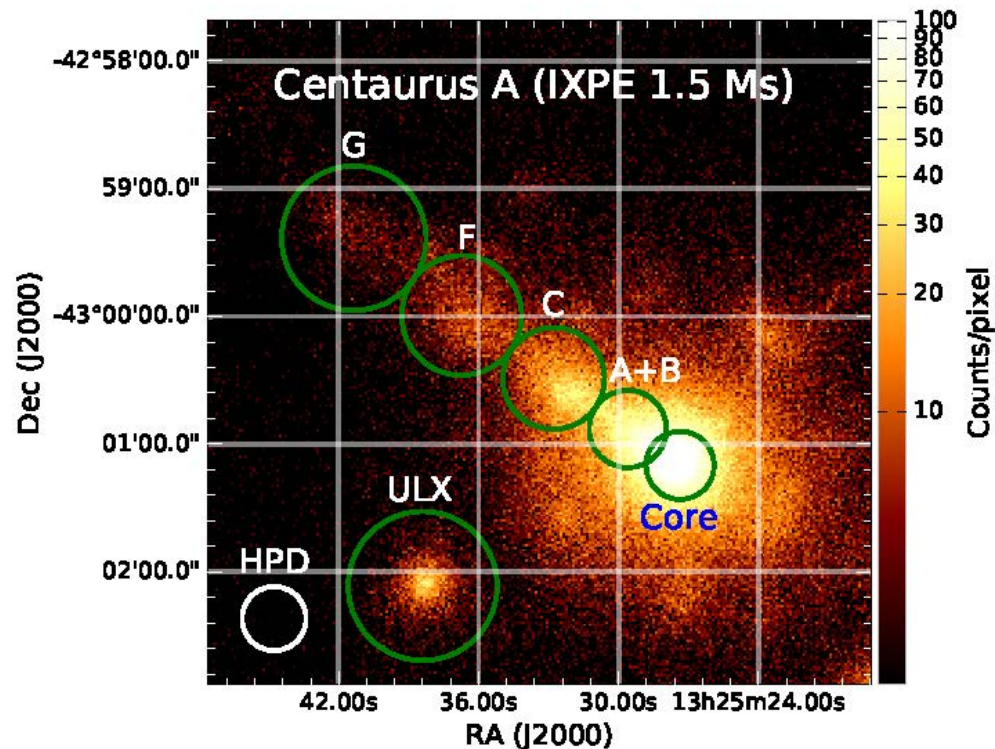
MAP MAGNETIC FIELD OF THE BRIGHTEST EXTENDED SYNCHROTRON SOURCES

■ Cassiopeia A (Cas A) Supernova Remnant (SNR)



CONSTRAIN POLARIZATION PROPERTIES OF AN IMAGED, BRIGHT AGN X-RAY JET

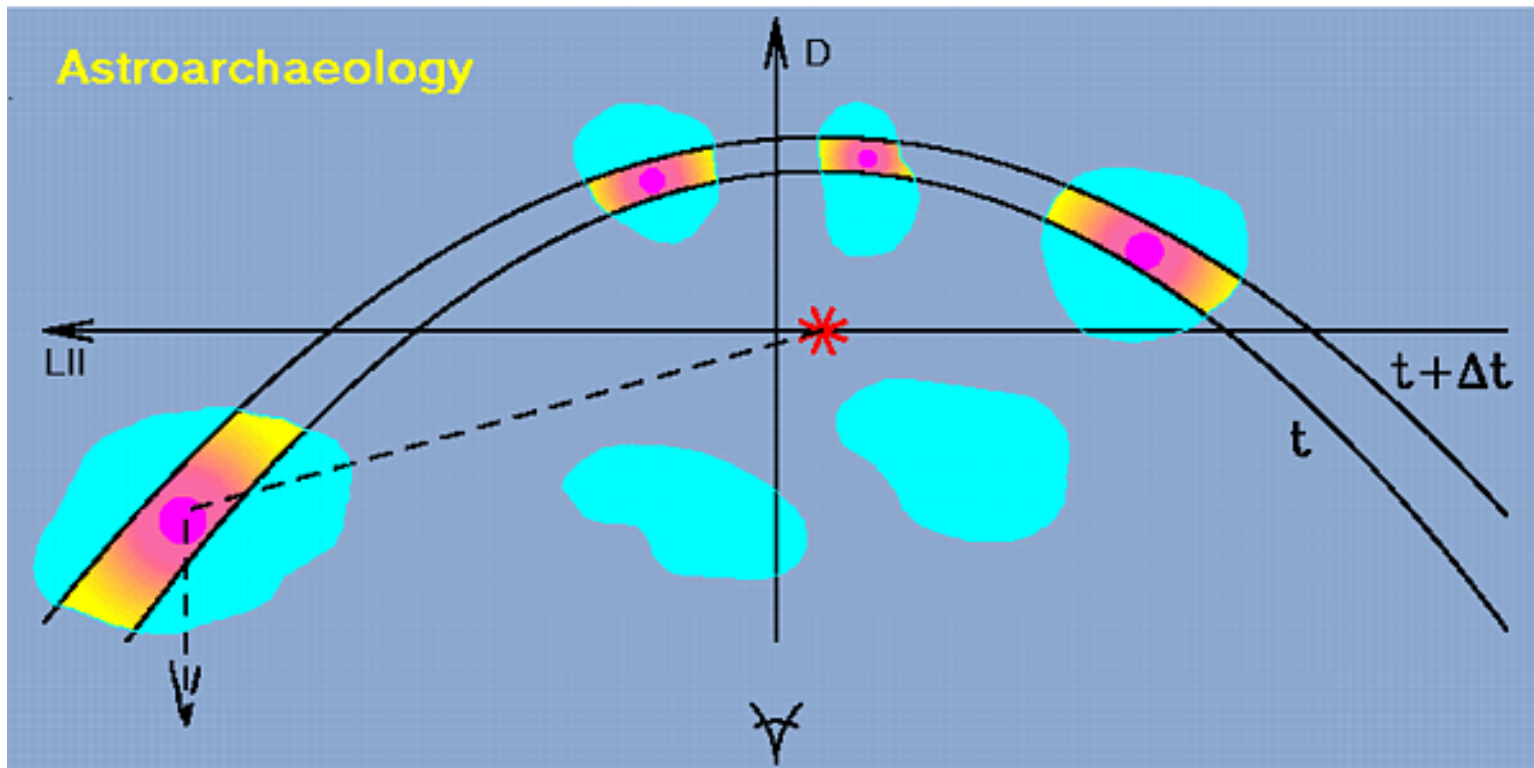
- Centaurus A (Cen A = NGC 5128) central region
 - 1.5-Ms IXPE (simulated) observation of Cen A



| Region | MDP ₉₉ |
|----------|-------------------|
| Core | <7.0% |
| Jet | 10.9% |
| Knot A+B | 17.6% |
| Knot C | 16.5% |
| Knot F | 23.5% |
| Knot G | 30.9% |
| ULX | 14.8% |

TEST REFLECTION-NEBULA HYPOTHESIS FOR X RAYS FROM GALACTIC-CENTER MOLECULAR CLOUDS

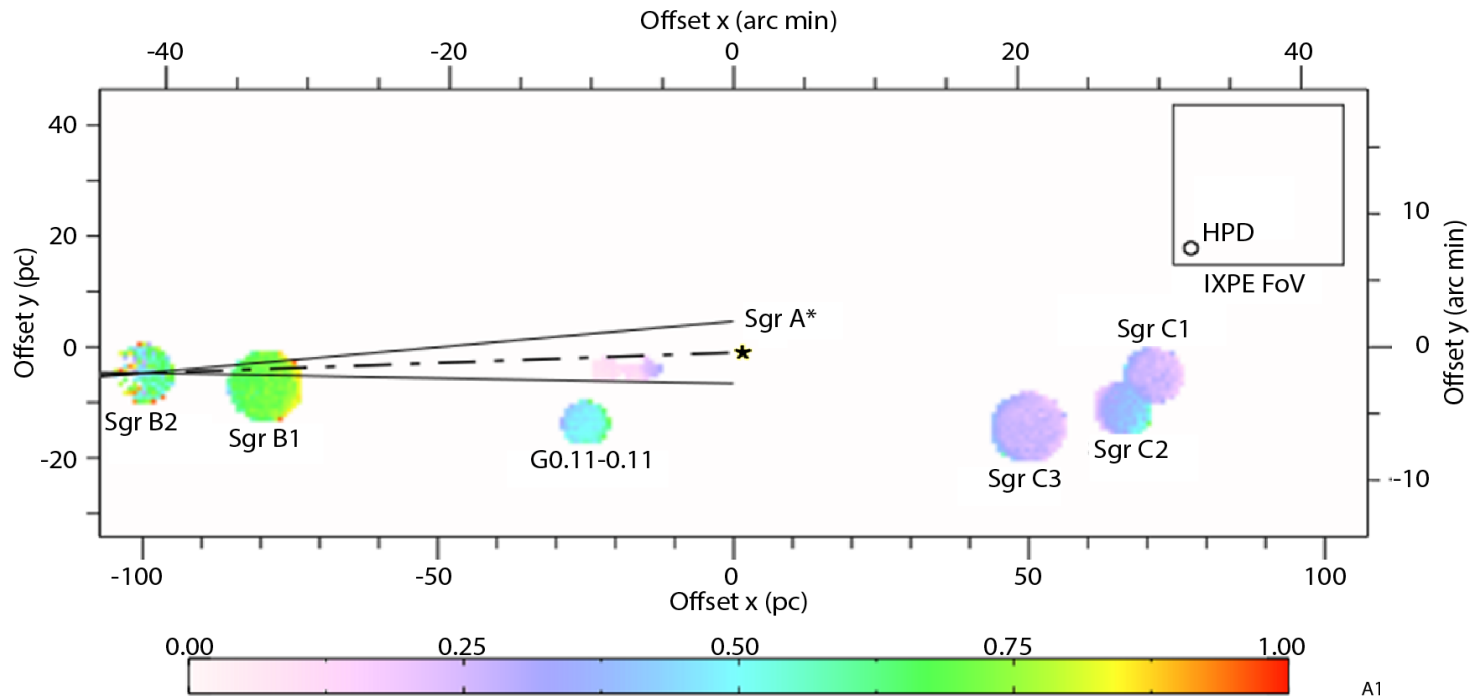
- **Does Sagittarius B2 (Sgr B2) echo Sgr A* x-ray activity?**
 - Time delay of a few-hundred years



TEST REFLECTION-NEBULA HYPOTHESIS FOR X RAYS FROM GALACTIC-CENTER MOLECULAR CLOUDS

■ Does Sgr B2 echo Sgr A* x-ray activity?

- Highly polarized x radiation, if reflected (Thomson scattered)
 - Polarization perpendicular to projected direction of source



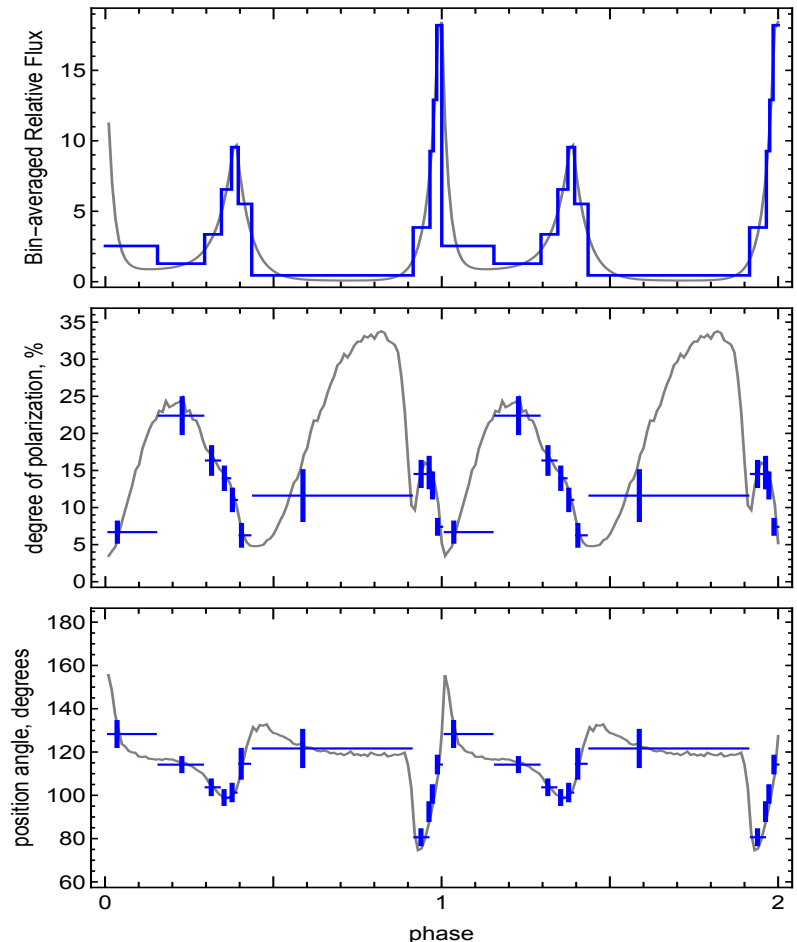
OBTAIN PHASE-RESOLVED POLARIMETRY OF BRIGHT PULSED X-RAY SOURCES

■ Isolated pulsars

- Example: Crab pulsar
 - In pulsar wind nebula (PWNe)
 - 34-ms pulse period
 - 140-ks IXPE (simulated) observation [blue]
 - Based upon visible-band polarization profiles [grey]

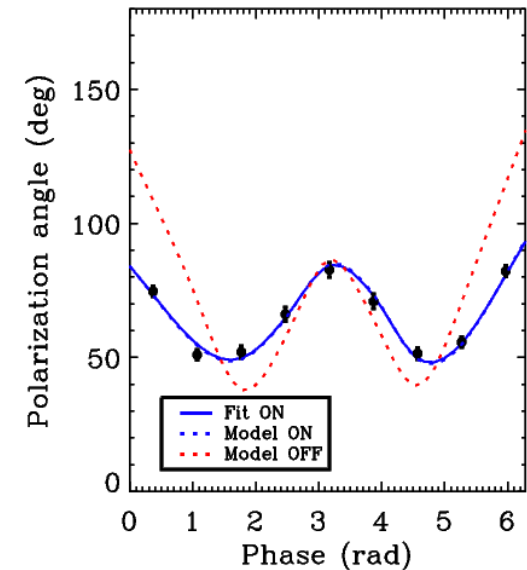
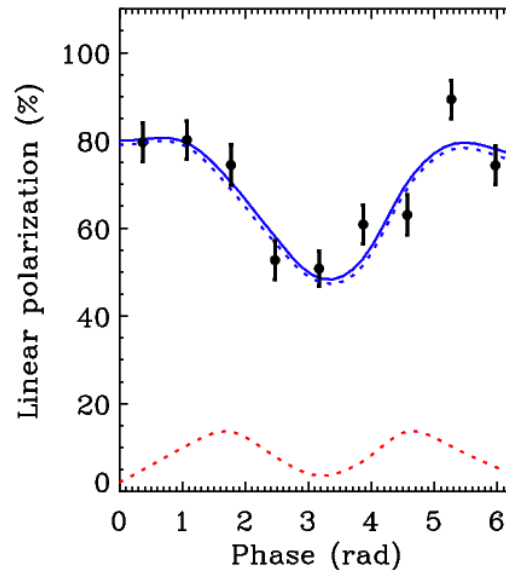
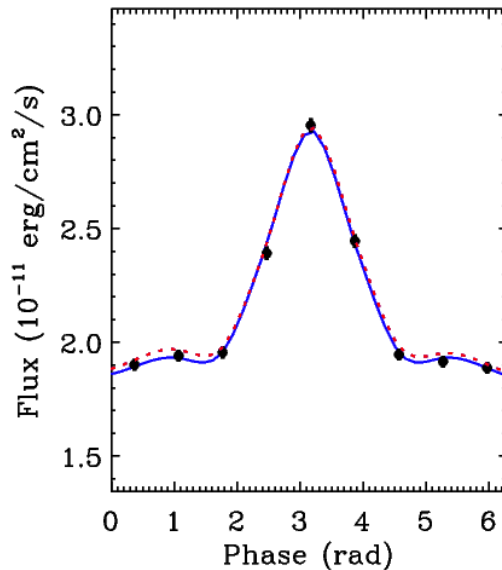
■ Accreting x-ray pulsars

- Classical (high-B) binaries
- Millisecond (low-B) binaries



MEASURE QUANTUM-ELECTRODYNAMIC BIREFRINGENCE IN A MAGNETIZED VACUUM

- **Magnetar (B_{surface} up to 10^{15} G)**
 - Example: 1RXS J170849.0-400910
 - 11-s pulse period
 - 250-ks IXPE (simulated) observation



MEASURE BLACK-HOLE SPIN FROM POLARIZATION ROTATION IN TWISTED SPACE-TIME

Microquasar in accretion-dominated state

- Example: GRS 1915+105
 - 200-ks IXPE (simulated) observation
 - Uses prior disk-orientation information from radio jet

